Improving Dynamic Information Exchange in Emergency Response Scenarios

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Francisco J. Quesada Real
University of Edinburgh
fquesada@inf.ed.ac.uk

Fiona McNeill
Heriot-Watt University
f.mcneill@hw.ac.uk

Gábor Bella
University of Trento
Gabor.Bella@unitn.it

Alan Bundy
University of Edinburgh
A.Bundy@ed.ac.uk

ABSTRACT

Emergency response scenarios are characterized by the participation of multiple agencies, which cooperate to control the situation and restore normality. These agencies can come from diverse areas of expertise which entails that they represent knowledge differently, using their own vocabularies and terminologies. This fact complicates the automation of the information-sharing process, creating problems such as ambiguity or specialisation. In this paper we present an approach to tackle these problems by domain-aware semantic matching. This method requires the formalisation of domain-specific terminologies which will be added to an existing system oriented to emergency response. Concretely, we have formalised terms from the UK Civil and Protection Terminology lexicon, which gathers some of the most common terms that UK agencies use in these scenarios.

Keywords

Query matching, dynamic information exchange, domain-aware matching, domain-specific terminologies, emergency-response extension

INTRODUCTION

Emergency Response (ER) scenarios usually involve the participation of several organisations which collaborate to address the crisis. Although collaboration is common in these scenarios, the exchange of information between participating organisations still presents several challenges.

Manoj and Baker identified in (Manoj and Baker 2007) that ER scenarios present communication challenges according to three categories: *technological* (technologies that agencies use to communicate between them, for example, when they do not use the same radio frequency); *social* (sharing and dissemination of information is problematic due to the lack of common vocabulary between response organisations) and *organisational* (how information flows across organisation's hierarchies). Allen et al. added that one of the most significant challenges regarding automated exchange of information (interoperability) is caused by problems with heterogeneous semantics (e.g., an H on a map is related to a hospital for the paramedics while for the fire brigade this represents an hydrant). This causes difficulties when they share maps (Allen et al. 2014). In part, these problems arise because each agency represents knowledge in a particular way, using its own terminology to describe its domain accurately.

The diversity of representations is not solely a characteristic of ER scenarios. This trouble appears in most areas, for example, it is a common problem in the fields of medicine or biology (Beisswanger and Hahn 2012). In order to tackle these problems researchers from the ontology matching field focus on finding solutions to these problems. See, for example, (Euzenat, Shvaiko, et al. 2007).

Essentially, these approaches try to match different words from diverse sources that are used for the similar purpose (words with similar meaning). Although there are many advances which allow the integration and understanding of resources expressed in different terminologies, there still are several problems that are unresolved. Examples are *ambiguity*, when the same word or symbol represents a different concept depending on the domain, or *specialisation*, when one terminology represents knowledge in a more detailed way than another one. Apart from the mentioned examples, there are others problems like the integration of *multilingual* resources (Rexha et al. 2016), mismatches due to *cultural aspects* (Gracia et al. 2012) (these are concepts specific of a region or a country and they do not exits or are different in other countries) or *large-scale evaluation* (Shvaiko and Euzenat 2013).

The implementation of matching techniques in ER scenarios is not trivial due to issues such as:

- *Privacy constraints*, which restrict the access to some parts of agencies' data sources. This impedes the possibility of carrying out matches between entire datasets, so it is necessary to assume that we have to manage with incomplete data.
- *Dynamic information*. The information is continuously changing so it is necessary to carry out the matching process on the fly.
- *Impractical prior alignment*. Pre-alignment is feasible and sensible for agencies interacting very frequently but intractable otherwise and impossible with agencies for which there was no anticipation of interaction prior to the response.

Despite these considerations, in ER scenarios there are many situations in which matching techniques can be useful. The situation we are particularly interested in is *querying*, where a source agency (the sending agency) sends a query to one or more other target agencies (the receiving agencies) to gather information that they need. If it does not know the data structures of the receiving agency/ies in detail, or they have changed, or a general query is sent to several target agencies, it is likely that this query will fail because it will be built without a precise knowledge of the data structures used by each target agency unless extensive pre-alignment has occurred.

(McNeill et al. 2014) proposed CHAIn, a system which makes use of ontology matching techniques to carry out query rewriting on the fly. CHAIn is located locally within the receiving agency, and is therefore able to access all of that agency's data without any security concerns. When a query comes in that fails to elicit a response, CHAIn will use matching techniques to find approximate matches within the receiving agency's data sources and rewrite the query accordingly, so that a relevant response can be returned to the sending agency. It might be considered as a first step of automating the exchange of information in ER scenarios. CHAIn is designed to act dynamically, and because it is located locally within each agency it does not require agencies to share their data beyond providing responses to queries, so addresses the two issues above. However, the issues of ambiguity and specialisation still remain because they arise from the specific contents of each data source.

This paper introduces an approach to improve the performance of CHAIn in the domain of ER, tackling ambiguity and specialisation by adding domain-aware (DA) semantic matching. Our hypothesis is that *adding DA semantic matching into CHAIn significantly reduces the mismatches produced by ambiguity and specialisation*. Moreover, this approach *helps to find correct matches that might otherwise be missed*. As a result, a new version of CHAIn with DA functionality will be released as domain-aware CHAIn (DA-CHAIn)[1].

Considering that we are going to use this system for data sharing between ER agencies, we also have to enrich it with some of the most common terms used in these scenarios. In particular, we have formalised some terms contained in the lexicon of the UK Civil Protection Terminology (UKCP)[2] in order to make these accessible to DA techniques.

The paper is organised as follows. The next section presents a motivating example. After that some basic notions about domain-aware matching are outlined in the following section. The approach of extending background knowledge by formalising domain-specific terminologies and the development of an ER extension are explained in next two sections. The following section introduces the evaluation methods that will be carried out to test the approach. The paper finishes with related work and conclusion sections.

MOTIVATING EXAMPLES

In ER scenarios such as natural disasters, agencies usually share information because one agency's information might be useful to another one. It is frequently the case that practitioners from different organisations call to other agencies' representatives to ask about the status of a specific incident.

[1]https://github.com/francisjqr/DA-CHAIn
[2]https://www.gov.uk/government/publications/emergency-responder-interoperability-lexicon

For example, in a flood scenario, ER agencies need to know information such as which roads are cut off, what is the forecast for next hours, what the levels of the rivers are, and so on. Currently, such work is carried out entirely through human interaction. We understood from our interactions with the Resilience Department of the Scottish Government that the typical approach is to write new and relevant information on whiteboards in the control room, and then using this information in the decision-making process.

Currently, this process is time consuming, and practitioners often miss pertinent data because they are not aware of its availability. This precarious method puts even more pressure on practitioners, who have to make decisions being aware that a wrong choice may be fatal for people's lives.

These issues could be significantly relieved by automating data sharing in ER scenarios. A major problem to be solved, however, is that every organisation has its own terminology. This is useful an important for agencies because these terms properly describe their tasks and work. However these terms may not be automatically compatible with data from other sources and may be misleading and difficult to understand for people from other domains.

For example, Figure 1 depicts how the fire brigade and the police represent different *Command Levels*.

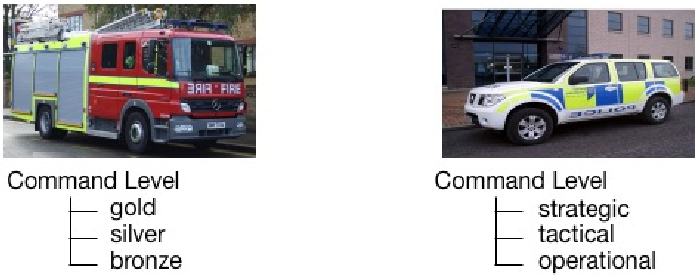

Figure 1. Example of diverse knowledge representation

We can see how they use distinct terms for referring to the same concepts. Attempting to infer a relationship between these terms automatically by using standard lexical resources would fail because they are not obviously related, and even for a human to link them depends on that person having domain-specific knowledge.

Another example of heterogeneity is ambiguity where the same word is used in several agencies' vocabularies, but the meaning is different depending on the organisation. Imagine an international emergency scenario where agencies from different countries are involved. If organisations from the United States (US) and the United Kingdom (UK) have to exchange information they will have a problem with the meaning of the acronym *CIA* because it is distinct depending on the source. Thus, for WordNet[3] (Fellbaum 1998) and the Government of the US, this acronym means *Central Intelligence Agency US*, while for the UK agencies (UKCP lexicon), this means *Community Impact Assessment*. Table 1 shows the meanings from both sources.

CIA	
WordNet 3.1	**UKCP Lexicon**
Central Intelligence Agency US	Community Impact Assessment
An independent agency of the United States government responsible for collecting and coordinating intelligence and counter intelligence activities abroad in the national interest; headed by the Director of Central Intelligence under the supervision of the President and National Security Council.	Procedure to identify the impact a police operation or response may have on communities, including actions necessary to overcome potential negative effects either before or after the deployment of resources, and to specify primacy for community engagement with respect to each element of the operation or response.

Table 1. Example of ambiguity

Yet another example is agencies using different degrees of knowledge representation (KR) in their vocabularies (specialisation), for example, when an amateur forecast society exchanges information with a professional forecast agency. In this situation, the professional agency may have a more detailed vocabulary than the amateur one, which

[3] WordNet is a domain-independent lexical resource. http://wordnet.princeton.edu

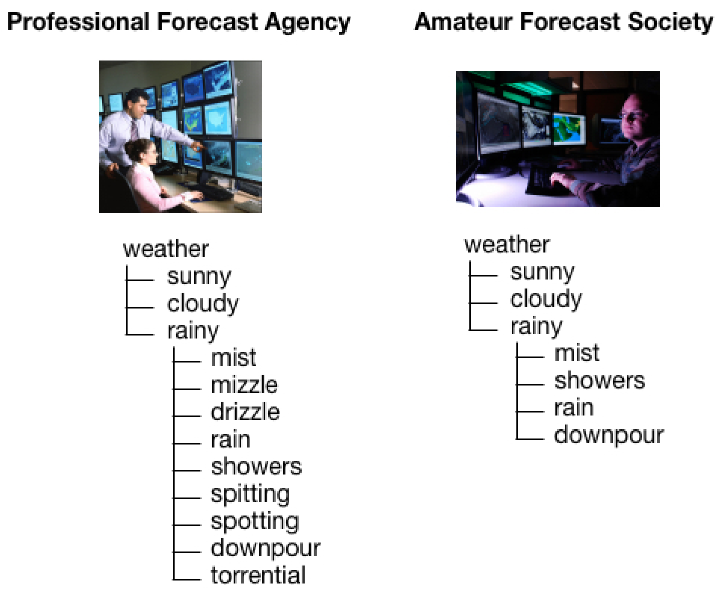

Figure 2. Example of specialisation

makes finding correspondences between the terms of both organisations non trivial. Figure 2 depicts part of the terminologies used by both organisations.

Keeping in mind these motivating examples, in next section we present an approach to tackle automation problems in the process of information exchange between agencies.

DOMAIN-AWARE DYNAMIC QUERY MATCHING

Problems such as those evoked in the previous section are typically solved by ontology matching techniques. Given two schemas with the terminologies of two agencies, the main purpose of ontology matching is to assign correspondences between the elements (nodes) of both schemas. These correspondences are called *matches or alignments* and indicate that two nodes are related. That is, they have similar meanings, so they belong to the same concept. An example of word matching might be the words *river* and *creek* because both words mean a kind of *watercourse*. In order to carry out the matching process, the matcher receives as input two schemas and produces as output the alignments between both schemas. The matcher needs a resource, the Background Knowledge (BK), which contains knowledge of the terminologies, in order to conclude whether or not the natural-language labels of nodes between the data schemas and the query schema have the same meaning.

This is the problem that CHAIn's matcher deals with. In the case of CHAIn it is matching the schema of an incoming query against the schema of a target data source, using both structural and semantic matching techniques. CHAIn is built on top of the Structure Preserving Semantic Matcher (SPSM) (Giunchiglia, McNeill, et al. 2008), which in turn is build on the semantic matcher S-Match (Giunchiglia, Shvaiko, et al. 2004). This matcher is designated for so-called lightweight ontologies (Giunchiglia and Zaihrayeu 2009) that are tree-shaped. SPSM adds standard tree-edit distance techniques (Bille 2005) and a structure-preserving constraint, which make the tool better suited to schema matching. S-Match uses WordNet as BK, taking advantage of the semantic relations defined there to carry out the semantic matching process.

WordNet (Fellbaum 1998) is one of the most extensive domain-independent lexical resources because of the huge number of nouns, adjectives and verbs that are included. Its main characteristic is that it is more focused on the meaning of words than on the form of words. This resource represents concepts by *synsets* which consists of sets of words which are synonyms. Thus, all elements of a synset are included in the same concept, and so they have the same meaning. WordNet is a directed acyclic graph formed according to the following semantics relations: *hypernymy* (superconcept of another concept, for example *motor vehicle* is the hyponym of *car*); *hyponymy* (subconcept of another concept, for example *car* is the hyponym of *motor vehicle*); *meronymy* (one concept is part of another one, for example *air bag* is meronym of *car*); *holonymy* (one concept has/includes another one, for example *car* is holonym of *air bag*).

However, as we discussed in the motivating example section, WordNet is only sufficient in very general situations and it will not be able to deal with ambiguity and specialisation when dealing with data sources using domain-specific terminology, hence the need for DA-CHAIn. First of all, in order to deal with specialisation, we are going to extend the current S-Match's BK adding domain-specific terminologies in order to enrich the BK with terms that ER agencies use to represent their knowledge. Secondly, we extend the matcher with *domain-based word sense disambiguation* functionality, based on our earlier work as presented in (Bella et al. 2016). This allows the matcher to reduce the ambiguity of terms based on domain information. This second aspect of domain awareness is not covered in this paper. These extensions allow us to tackle both ambiguity and specialisation, as depicted in Figure 3.

For example, regarding the ambiguity problem described in the previous section (see Table 1), if the matcher knows the domain of the acronym *CIA*, it can decide whether the term refers to the US agency or to the meaning in the UKCP lexicon. In addition, this extension is also relevant to matching words that are not related yet, because of the lack of lexical information of these words in the BK (see Figure 1) and to infer matches when the specialisation problem appears (see Figure 2).

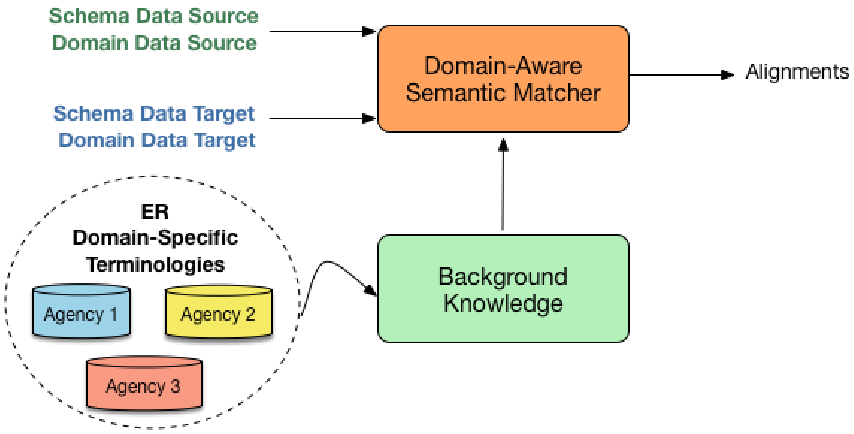

Figure 3. General schema of a DA matcher with the ER extension

BACKGROUND KNOWLEDGE EXTENSION PROCESS

The extension of a BK with domain-specific terminologies is useful for tackling specialisation. However, the selected terms have to meet some constraints to preserve BK's integrity (maintaining consistency between elements' relations). The process of extending a BK consists of the following steps:

1. Selection of terms.
   First of all, it is necessary to select the terms to formalise. These should be terms that are specific to a particular domain (e.g. the fire brigade, the police or the army). For this work, we are taking terms from the UKCP lexicon.

   Each of these terms must have *label* (primary term), *definition* and *provenance*. An example of term may be *agency*:

   - *Primary term*: Agency.
   - *Definition*: A generic term, widely used as synonymous with organisation.
   - *Provenance*: Civil Contingencies Secretariat (CCS).

   Optionally, there are other attributes that might be interesting to formalise such as *acronym, version, notes* or the *jurisdiction* to which the term is restricted.

2. Check that new terms are not represented in the BK.
   Once the terms to formalise are selected, the following phase involves going through every single term to verify whether it is currently represented in the BK or not. This point is crucial because if we create new concepts or senses that already exist in the BK we are increasing polysemy and redundancy, and in some cases violating the BK integrity. For this reason, we need strong arguments for creating new entries in the BK.

This phase is formed by two tasks:

(a) *Identifying term's hypernym/s.* Analysing the definition of the given term (meaning), we can identify the hypernym of the term. It is important this identification to understand the meaning of the term and how can it be integrated in the BK.

(b) *Linking the term to existing terms in the BK.* At this point we have to seek our term (word) in the BK and check whether it is included or not, and if it appears, it is necessary to verify whether the term's meaning in the BK is the same as our term's definition. The decisions to make depending on each case are described as follows:

  a *The term is not in the BK.* After looking for the term in the BK the search did not return any result, so our term's *label* does not exist in the BK. At this point, two cases are possible:
  - *The concept is currently represented in the BK*, so it is necessary to link the new term to the concept.
  - *The concept is not represented in the BK*, therefore the new term is added to the BK creating an associated concept.

  b *The term is currently in the BK.* The search of the term in the BK has retrieved one or more senses, so we have to check if any sense has the same meaning as our term. This new verification produces two new scenarios:
  - *The term has the same meaning of a sense*. Because the term is currently in the BK with the same definition as our term, we do not have to do anything.
  - *No sense has the same meaning as the term.* In this case we have to double-check if the concept is represented in the BK or not. This is the same case as the scenario described before in "2.(b).a" (*The term is not in the BK*), so we have to follow the mentioned guidelines and act depending on the case. A new sense of the word has to be added independently whether it is necessary to create a new concept or not.

3. Double-check terms relations.
Once all new terms are added into the BK, in this phase we have to double-check that all semantic relations have been taken into account. Essentially, in the previous phase we identified the semantic relations between each new term and the terms included in the BK. Nonetheless, it is also necessary to specify the relations of the new terms that are interrelated. For example, in the UKCP there are terms that include in their definitions others terms defined in the lexicon or terms that are synonyms. Therefore, we have to go again through all new terms in order to ensure that all of these relations are considered.

4. Representation in the BK format.
Once we have the terms that we are going to formalise as well as their relations, the next step consists of representing these terms in the BK's format. The output of this step is a file compatible with the BK.

5. Integration of these terminologies into matcher's BK.
In this step, the file which contains the specific terms is plugged in the BK. In our case, we are using a tool called DiverCLI[4] which is capable of plugging new terms into WordNet.

EMERGENCY RESPONSE EXTENSION FOR WORDNET

The process explained in the previous section has been applied to develop an ER extension for WordNet. In particular, we have selected terms from the UKCP lexicon. This lexicon is a collection of more than 725 terms used by UK agencies during ER scenarios. Each entry in the lexicon contains: the label of the term, denoted as primary term; version of inclusion or revision; source and definition. Moreover, there are some terms that also have abbreviations or acronyms, notes on definition and the jurisdiction to which the term is restricted. There are some definitions which reference particular terms that have been defined in the lexicon. These terms are represented in bold to be distinguished from general terms. Table 2 shows an example of the terms: agency, air ambulance, medevac and responder as they appears in the UKCP lexicon. Specifically, the entries of the terms in this example come from two different sources: the Civil Contingencies Secretariat (CCS) and the Environment Agency (EA). The formalisation of this example is currently online[5].

[4]http://diversicon-kb.eu/tools#divercli
[5]https://github.com/francisjqr/ER-Wordnet-Extension/blob/master/illustrativeExample.xml

Primary Term	Abbrev.	Vers.	Source	Definition	Notes	Jurisdiction
Agency		2.0	CCS	A generic term, widely used as synonymous with organisation.		
Air ambulance		1.0	CCS	Aircraft (usually a helicopter) used primarily to transport medical or paramedical staff to the **site** of an **incident** or **emergency** and **casualties** to specialist trauma centres and/or **designated hospitals**		
Environment Agency	EA	2.0	EA	The Environment agency's role is to protect and enhance the environment as a whole in England and Wales. As part of this role, they are also a nuclear regulator in respect of controlling discharges to the environment. An executive non-departmental public body responsible to the Secretary of State for **DEFRA**.	Note: in Scotland, this role is performed the SEPA, the Scottish Environment Protection Agency.	*England and Wales*
Medevac		1.0	CCS	Abbreviation for Medical Evacuation (of casualties by air)		
Responder		1.0	CCS	Organisation required to plan and prepare a response to an **emergency**.		

Table 2. Entries in the UKCP lexicon

We have been collaborating with the Resilience Department of the Scottish Government to elaborate an ER extension for WordNet. We have released a first version with 100 terms of the UKCP lexicon (Quesada Real 2017), which is a representative subset of the whole lexicon. This resource is available on a repository[6] which will gather all the ER extensions that we will develop for our research. These extensions can be used by the ER community so that agencies can use them for their own purpose, allowing organisations to carry out automated reasoning or processing in ER scenarios.

EVALUATION

The hypothesis to be evaluated in our research is that *adding DA semantic matching into CHAIn significantly reduces the mismatches produced by ambiguity and specialisation*. Once we have finished developing DA-CHAIn and integrated the ER extension into it, we will need to evaluate the performance of the system. To do this, we are going to define several case studies, which represent ER scenarios of prior events, together with practitioners from the Resilience Department of the Scottish Government. These will be based on the floods that happened in Scotland in the winter of 2015/2016. These case studies will represent the interaction between ER agencies with heterogeneous KR in situations where the communication failed due to ambiguity or specialisation problems. We are going to use agencies' schemas as well as their data to define gold standards for the evaluation.

Our approach will be evaluated attending to two criteria. On the one hand, it is necessary to test the performance of S-Match with DA functionality. These tests will consist of comparing the precision and recall, concerning the defined gold standards, of both matcher's versions. On the other hand, after the matcher evaluation, we have to evaluate the performance of DA-CHAIn comparing it with CHAIn. To do so, the same case studies will be run in both systems and several practitioners, based on their experience and expertise, will evaluate the relevance of the retrieved responses. Since this process is quite subjective, we have to recruit a panel of practitioners for the evaluation.

RELATED WORK

The work in this paper is concerned with the extension of existing matching techniques with domain-aware information in order to tackle problems like ambiguity and specialisation in ER scenarios.

[6]http://diversicon-kb.eu

There are many proposals for generating matching between diverse ontologies (Shvaiko and Euzenat 2013). For this reason, we have to establish what approach or combination of approaches adjust better to our specific problem (Otero-Cerdeira et al. 2015). Thus, we build our system on CHAIn, defined in (McNeill et al. 2014), which takes into account the characteristics of ER scenarios. Thus, it tackles the heterogeneity of structured terms and carries out dynamic and local matching, which were crucial aspects in our decision.

Although CHAIn produces good results, there are occasions when it fails to find mappings, in part due to issues of ambiguity and specialisation, a common problem in ontology matching (Sabou et al. 2006). These troubles are caused by the lack of domain information in situations where these issues appear. Indeed, these problems increase in scenarios where there are agencies from multiple domains. There have been attempts from the ontology matching field trying to solve these problems by enriching matching approaches with knowledge of ontologies' domains (Slabbekoorn et al. 2012). One example of these works was proposed by McCrae et al., who used domain information from Wikipedia[7] articles to improve the performance of adapting an ontology into a different cultural context in multilingual problems for machine translation (McCrae et al. 2016). In the same way, León-Araúz and Farber present an approach to describe concepts and terms from different domains and with cultural constraints to carry out cross-lingual correspondences using context features (León-Araúz and Faber 2014).

Even though these techniques can improve the correctness of matches, it is necessary that our BK identifies which terms belong to each domain. One of the most extended online lexical resources and the one used by CHAIn's matcher as BK is WordNet (Fellbaum 1998). There are some works focused on providing WordNet with domain information. Magnini and Cavaglià integrate subject field codes into WordNet, annotating noun synsets. This allows the grouping of synsets of the same domain (Magnini and Cavaglia 2000). Likewise, Bentivogli et al. develop the WordNet Domain Hierarchy, which is a language independent resource, composed of 164 domains such as Architecture, Sport or Medicine (Bentivogli, Forner, et al. 2004). In the same way, Strapparava and Valitutti propose tagging synsets which represent affective meanings, in order to provide a lexical representation of affective knowledge. González et al. for their part improve WordNet domains by an automatic graph-based method which propagates domain information through the knowledge base (Gonzalez-Agirre et al. 2012). Also, Gella et al. construct a domain-specific and multilingual corpora aligning WordNet domains and topics with Wikipedia categories (Gella et al. 2014). Moreover, there are some works which extend WordNet with specific terminologies from architecture (Bentivogli, Bocco, et al. 2004) or maritime domain (Roventini and Marinelli 2004). Despite the number of domains that currently exist in WordNet, the ER domain is not included. The creation of this domain as well as an extension with ER terminologies might be beneficial for those agencies that use WordNet resource for different purposes, e.g. natural language processing. Furthermore, the adaptation and definition of DA matching techniques entail a theoretical contribution in the ontology matching field. The integration of DA functionality into CHAIn supposes an advance to improve the communication between agencies in ER scenarios reducing problems derived by ambiguity and specialisation.

CONCLUSIONS AND FURTHER WORK

The difficulty of exchanging information between agencies in ER scenarios because of the heterogeneity of KR makes it necessary to develop resources which help to palliate the problems these leads to.

In this paper, we have presented a proposal for tackling these by DA semantic matching. Concretely, we focus on ambiguity and specialisation problems. This approach will be implemented in the query rewriting system CHAIn, as DA-CHAIn version. To do so, we have produced an ER extension from terminologies contained in the UKCP lexicon, in order to extend the BK of CHAIn's matcher. This reduces the communication problems mentioned above.

Regarding further work, this resource will be used to improve semantic matching between ER organisations' schemas. Moreover, it will be beneficial to increase the ER extension with terms from more organisations, including agencies from different countries. The next step will be towards working with multilingual terminologies which are crucial to improve the exchange of information in cross-border or international emergency response scenarios.

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[7] https://www.wikipedia.org

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